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<b>(21) International Application Number:</b> PCT/PL98/00023 <b>(22) International Filing Date:</b> 3 June 1998 (03.06.98) <b>(30) Priority Data:</b> P.320392 5 June 1997 (05.06.97) PL <b>(71) Applicant (for all designated States except US):</b> CENTRUM BADAN WYSOKOCIŚNIENIOWYCH POLSKIEJ AKADEMII NAUK [PL/PL]; ul. Sokołowska 29/37, PL-01-142 Warszawa (PL). <b>(71)(72) Applicants and Inventors:</b> ŁUCNLIK, Bolesław [PL/PL]; ul. Gwiazdzista 27 m 93, PL-01-651 Warszawa (PL). SUSKI, Tadeusz [PL/PL]; ul. Lachmana 2 m 70, PL-02-786 Warszawa (PL). WRÓBLEWSKI, Mirosław [PL/PL]; ul. Nowolipie 26 m 85, PL-01-011 Warszawa (PL). <b>(72) Inventors; and</b> <b>(75) Inventors/Applicants (for US only):</b> POROWSKI, Sylwester [PL/PL]; ul. Wieniawskiego 5/7, PL-01-572 Warszawa (PL). BOCKOWSKI, Michał [PL/PL]; ul. Klaudyń, 32 m 311, PL-01-168 Warszawa (PL). GRZEGORY, Izabella [PL/PL]; ul. Nałkowskiej, 9 m 10, PL-01-886 Warszawa (PL). KRUKOWSKI, Stanisław [PL/PL]; ul. Zaranie		<b>(81) Designated States:</b> JP, US, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).  <b>Published</b> <i>With international search report.</i> <i>Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i>
<b>(54) Title:</b> THE METHOD OF FABRICATION OF HIGHLY RESISTIVE GaN BULK CRYSTALS  <b>(57) Abstract</b>  This method according to the invention allows the fabrication of bulk GaN crystals of high specific resistivity. This is achieved by the crystallization of GaN from the solution of atomic nitrogen in molten mixture of metals, containing gallium and Periodic Table group II metals: magnesium, calcium, zinc, beryllium, cadmium, under high pressure of nitrogen, in the temperature gradient. These crystals can be used to fabrication of excellent single crystalline GaN substrates for deposition of the homoepitaxial layers and structures for the optoelectronic applications.		

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## **The method of fabrication of highly resistive GaN bulk crystals**

### **Field of the Invention**

This Invention relates to the method of fabrication of highly resistive GaN bulk crystals for manufacturing of optoelectronic devices.

### **Background of the Invention**

According to the present state of the art of growth of single crystals there are not known methods of manufacturing of highly resistive GaN bulk crystals.

### **Object and Summary of the Invention**

According to the Invention, GaN crystallization is effected in the solution of atomic nitrogen in molten mixture of the metals containing gallium in the concentration not lower than 90 at % and at least one of Periodic Table group II metals: Mg, Ca, Be, Zn, Cd. in the concentration: 0.01 - 10 at % in order to reduce the concentration of free electron carriers in the crystal by change of microscopic growth mechanism leading to the improvement of the stoichiometry and compensation on nonintentionally introduced donor impurities. The process is conducted under nitrogen pressure 0.5 - 2.0 GPa and in the temperature 1300 - 1700 °C in order to assure the stability of GaN and high concentration of nitrogen in liquid solution.

Crystallization is conducted with the temperature gradient not smaller than  $10^{\circ}\text{C}/\text{cm}$ , which assures low supersaturation in the growth zone, necessary to obtain GaN crystal growth velocity lower than  $0.2\text{ mm/h}$ , necessary for stable growth of large size crystals.

In the results of the growth process hexagonal GaN plate-like crystals are obtained, having the specific resistivity  $10^4 - 10^8\ \Omega\text{cm}$ , characterized by high structural quality and the lattice parameters close to the perfect crystal. These so obtained crystals, are not available at present, and can be used as perfect substrates for unstrained homoepitaxial GaN layers.

The subject of the Invention is demonstrated on the examples of applications.

#### Example 1

The molten mixture of semiconductor purity metals consisting of 99.5 at. % of gallium and 0.5 at. % of magnesium is poured into the vertically configured graphite crucible under the shield of inert gas. The crucible is located into the three-zone graphite furnace which is then positioned inside the high pressure vessel, which in the first stage is evacuated to the vacuum level of  $10^{-5}$  Torr. The system is annealed in the vacuum in the temperature  $800^{\circ}\text{C}$  during 12 hours. After the annealing, the vessel is filled with nitrogen of 6N purity achieving the initial pressure of 10-15 MPa. Then the gas is compressed to the pressure of 1.5 GPa and after the compression, the crucible is heated to the temperature of  $1550^{\circ}\text{C}$  in such a way that the temperature along the crucible axis is kept constant. Then the temperature of the lower end of the crucible is lowered by  $30^{\circ}\text{C}$  obtaining the temperature gradient along the axis of the crucible. These conditions of the process are preserved during the period of 120 hours. After

120 of crystallization, the system is cooled down with the rate of 5°C/min to the room temperature and after that the nitrogen pressure is lowered to the atmospheric pressure. After the extraction of the crucible from the high pressure vessel, the crucible is warmed up to the temperature 50°C and the molten metal is poured out from the crucible. At the bottom of the crucible there are GaN crystals in the form of hexagonal platelets of the size of 6 - 8 mm. The GaN crystals are extracted from the crucible and etched in aqua regia in order to remove the remaining part of the metal.

GaN crystals, obtained in this process characterize by the specific resistivity equal to  $10^6 \Omega\text{cm}$  and high structural quality. The halfwidth of (0004) reflection of x-ray  $\alpha\text{CuK}$  line is 20 - 30 arc sec, and the a and c lattice parameters are very uniform and are equal to: 3.1877 Å and 5.1848 Å, respectively.

We claim:

1. The method of fabrication of highly resistive GaN bulk crystals, characterized by crystallization from the solution of atomic nitrogen in the molten mixture of metals, containing gallium in the concentration not lower than 90 at % and the Periodic Table group II metals magnesium, calcium, zinc, beryllium, cadmium in the concentration of 0.01 - 10 at% under the nitrogen pressure 0.5 - 2.00 GPa.
2. The method of fabrication of highly resistive GaN bulk crystals according to Claim 1 characterized by the crystallization temperature 1300 - 1700°C.
3. The method of fabrication of highly resistive GaN bulk crystals, according to Claim 1 characterized by the temperature gradient not higher than 10°C/cm.

# INTERNATIONAL SEARCH REPORT

Internat	Application No
PCT/P	/00023

## A. CLASSIFICATION OF SUBJECT MATTER

IPC 6 C30B9/00 C30B29/40 C30B11/00

According to International Patent Classification(IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 C30B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P, X	PATENT ABSTRACTS OF JAPAN vol. 98, no. 5 & JP 10 007496 A (HITACHI CABLE LTD ) see abstract ---	1-3
X	WO 95 04845 A (CENTRUM BADAN WYSOKOCISNIENIOWYCH) 16 February 1995 see page 11, line 3 - line 22; example 1 ---	1-3
X	FR 2 313 976 A (LABORATOIRES D'ELECTRONIQUE ET DE PHYSIQUE APPLIQUEE LEP) 7 January 1977 see page 2, line 8 - line 9; claim 1 --- -/--	1-3

☒ Further documents are listed in the continuation of box C.

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## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	POROWSKI ET AL: "Thermodynamical properties of III-V nitrides and crystal growth of GaN at high N2 pressure" JOURNAL OF CRYSTAL GROWTH., vol. 178, 2 June 1997, pages 174-188, XP004084984 AMSTERDAM NL see page 181 ---	1-3
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Information on patent family members

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PCT/PL/00023

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